 Printed in U.S.A.

RELATIONSHIP BETWEEN SKIN TEMPERATURE AND THE INSENSIBLE PERSPIRATION OF THE HUMAN SKIN*

F. A. J. THIELE, DRS. AND K. G. VAN SENDEN, DR.

In recent years a number of methods have been developed for the quantitative determination of the water loss (insensible perspiration) of the human skin (1).

The results of measurements carried out in a large number of test subjects, both men and women, under different climatic conditions, show wide variations: 3 to 25 $\mu g\ H_2O \cdot cm^{-2} \cdot min^{-1}$ on the forearm and 30 to 150 $\mu g\ H_2O \cdot cm^{-2} \cdot min^{-1}$ on the palm of the hand. These experimental data suggest that external factors contribute considerably to these differences. Factors responsible for these differences have been investigated.

METHODS AND APPARATUS

Measurements were carried out in a climate room in which both humidity and temperature could be adjusted. The accuracy of a chosen temperature is ±0.25°C and the humidity is ±2%.

Continuous measuring methods were chosen, to obtain a detailed picture of the processes involved, and to keep the influence of the measuring system on both the skin and the processes taking place as constant as possible.

Measurement of the water loss

A small metal cup is pressed lightly against the skin surface with special adhesive cotton strips. A constant stream of dry nitrogen gas is passed through this cup. The water vapor exuded by the skin is transferred by the carrier gas, and determined electrolytically with an electrolytic moisture meter (Meeco).†

By converting the determination of the amount of water to an electric measurement, registration on a Kipp BD.2 recorder‡ is possible. From these recordings the water loss curves have been plotted.

Temperature measurements

Yellow Springs Thermistors§ (No. 402 or 421) are mounted inside the cups in such a way that a constant contact pressure of the thermistor head on the skin is ensured (2). For measuring skin temperatures outside the cups, the Yellow Springs Thermistors (No. 408) or a Thermistan¶ glass-embedded thermistor are used. The ambient temperature is determined with a Yellow Springs Thermistor (No. 405).

By using thermistors the temperature measurements are converted to electric measurements, which are likewise registered on a Kipp BD.2 recorder. From these recordings and with suitable calibration curves, the temperature curves are plotted.

EXPERIMENTAL

Measuring area

The volar side of the forearm is divided into 5 measuring areas, as shown in Fig. 1.

Water loss and temperature measurements are carried out on these five areas after one hour acclimatization of the test subjects in the climate room, at comfortable conditions (23° C and 50% R.H.).

The temperature of all measuring areas, left as well as right, were the same (within 0.3° C) but the water losses decrease with the distance from the measuring area to the wrist.

If the test subject stays for some hours in a climate room, adjusted at 15° C and 70% R.H., the water losses at all measuring areas tend to become equal, after an initial decrease. The skin temperature, however, decreases as the measuring area is nearer to the wrist.

From this it follows that the site of the measurement is important. In our experimental results, the measuring areas have, therefore, always been mentioned.

RESULTS

Measurement on one forearm

Fig. 2 shows the course of the water loss and the skin temperatures with time at measuring area 3 of a test subject in the climate room, in comfortable conditions.

Covering the forearm with a towel, baring this forearm, fanning air at room or higher temperatures over the upper arm or the palm of the hand—that is *not* at the actual site of the measurement—or cooling by lowering the temperature in the climate room are rapidly followed by a change in skin temperature. A change in the water loss follows about 30 seconds after a change in skin temperature has been

Received for publication December 15, 1965.

* From the Unilever Research Laboratory, Vlaardingen, The Netherlands.

† Manufacturers Engineering and Equipment Corp. Warrington, Penna. (U.S.A.)

‡ Kipp, N. V. Delft (The Netherlands)

§ Yellow Springs Instrument Co. Yellow Springs, Ohio (U. S. A.)

¶ Ferrix, Nice (France 98 Av. Saint-Lambert recorded. After each alteration of the external conditions, both skin temperature and water loss tend to attain equilibrium values.

In Fig. 3 the water loss curves are given for two measuring areas on one forearm, *viz.* between measuring areas 1 and 2 as well as 3 and 4. We observe again an influence, from changes in the external conditions. Both curves run about parallel with a difference in water loss values of 2 to 3 $\mu g\ H_2O \cdot cm^{-2} \cdot min^{-1}$.

If Fig. 2 shows that there is a relationship between skin temperature and water loss, Fig. 3 illustrates once more that the measuring site is one of the factors which determine the value of the water loss ultimately recorded.

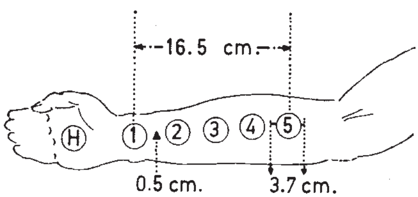

FIG. 1. Schematic drawing of the forearm showing 5 measuring areas; measuring area (3) is the midpoint between wrist and elbow.

Measurements on both forearms

If simultaneous measurements at area 3 are carried out on both forearms, and during the experiment the temperature in the climate room is lowered, almost equal water loss and temperature curves are recorded.

The water loss curves are given in Fig. 4, and the corresponding temperature curves in Fig. 5. The curves plotted for the right forearm, are invariably somewhat higher than those for the left one for this subject. Fig. 5 shows strikingly the fluctuating course of the skin temperature. Particularly the curve of the left forearm—in which case the skin temperature was recorded immediately next to the cup on the skin—clearly demonstrates these fluctuations. It is very likely that they are caused by variations in the ambient temperature. These fluctuations occur when the temperature of the climate room changes periodically. It should be

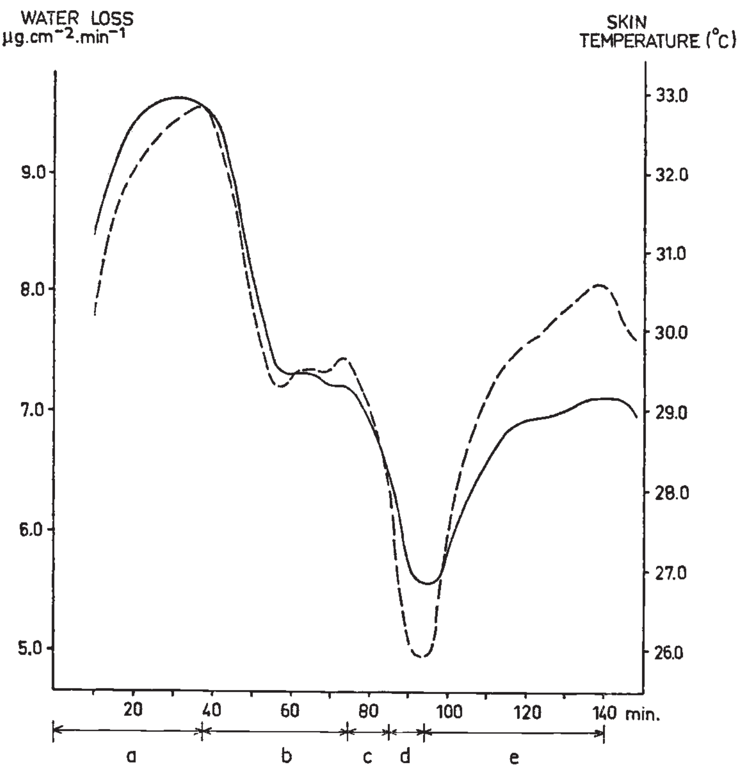

FIG. 2. Changes in water loss (——) and skin temperature (- - - -) at the measuring area 3 under the influence of cooling and heating [Subject A]. Forearm covered with a linen towel (a); forearm uncovered (b); fanning of the hand at a distance of 100 cm (c) and 25 cm (d); forearm and hand covered with a linen towel (e).

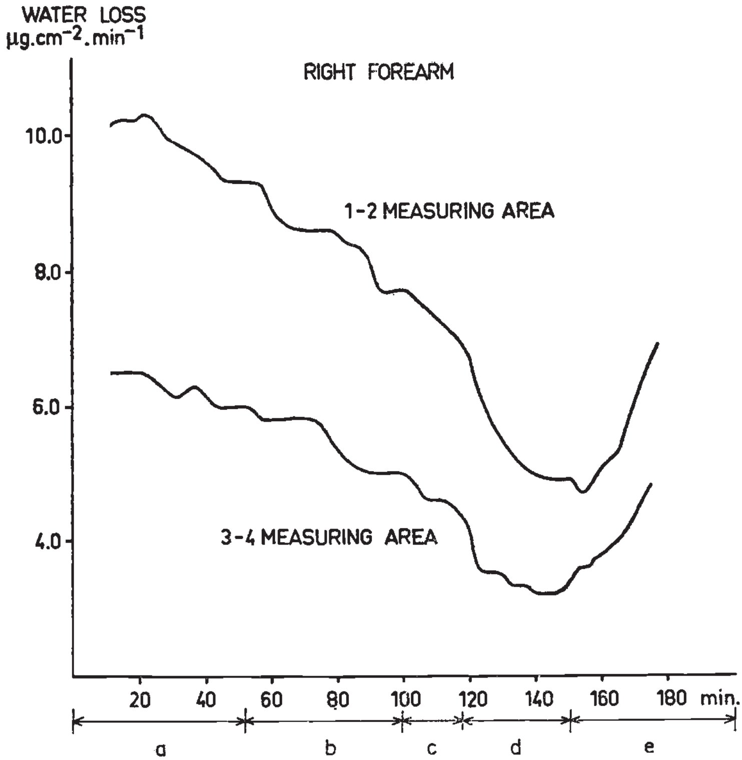

FIG. 3. Changes in the water losses at two measuring areas (between measuring area 1 and 2 and between 3 and 4) under the influence of cooling [Subject B]. Forearm uncovered (a); temperature drop in the climate room (b); fanning of the upperarm (c); fanning of the forearm (d); temperature increase in the climate room (e).

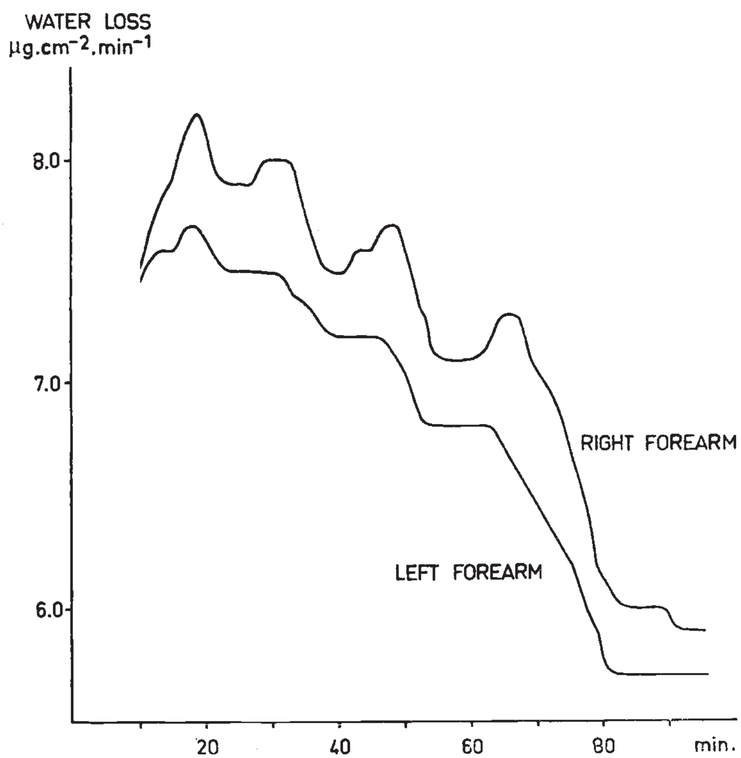

FIG. 4. Changes in the water losses at the measuring area 3 of the left and right forearm under the influence of cooling [Subject A]. These curves were recorded together with those of Fig. 5.

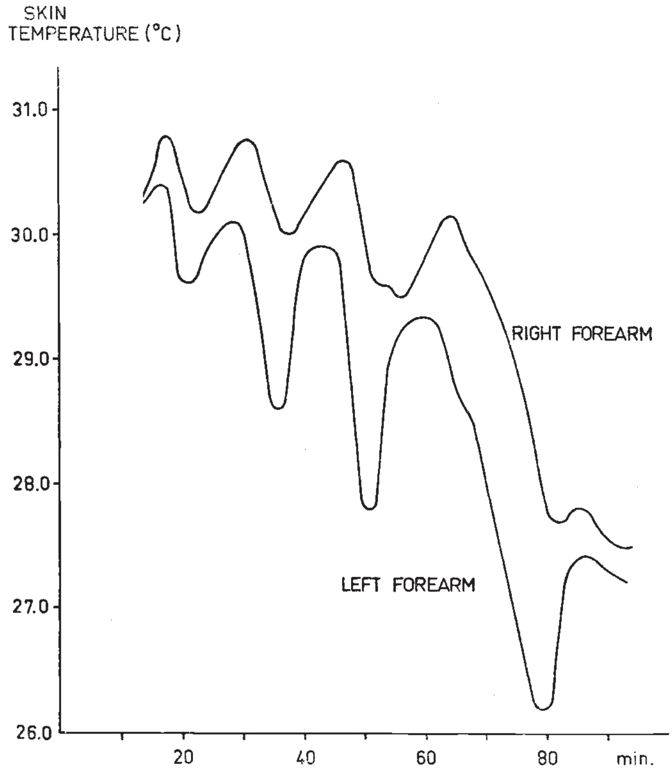

FIG. 5. Changes in the skin temperatures at measuring area 3 of the left and right forearm under the influence of cooling. On the right forearm the temperature was measured in the cup, on the left forearm outside the cup [Subject A]. These curves were recorded together with those of Fig. 4.

noted that these measurements were carried out on one of our most temperature-sensitive test subjects. Fig. 5 further shows that temperature measurements inside or outside the cup give only small differences, probably also caused by differences in contact-pressure of the thermistors.

Measurement on the palm of the hand

Measurements on the palm of the hand and on the forearm give similar reaction patterns. At a skin temperature of 21° C, a water loss varying from 15 to 25 $\mu g\ H_2O \cdot cm^{-2} \cdot min^{-1}$ was observed. At temperatures of ca. 32° C, however, values were recorded which are higher than 150 $\mu g\ H_2O \cdot cm^{-2} \cdot min^{-1}$.

These high values are mainly caused by increased sweat gland activity.

DISCUSSION

From the results of our experiments it appears that a relationship exists between skin temperature and water loss.

The supply of water to the extravascular tissue is effected via the vascular bed by capillary filtration (3, 4, 5). Moreover, it is well-known that the blood flow in skin and muscle is controlled by vasomotor mechanisms (6, 7). Contraction of those blood vessels which provide and regulate the supply of heat to the surface of the skin will result in decreased capillary circulation. Through this mechanism the heat supply is decreased and skin temperature drops. However, vasoconstriction will also reduce the known determinants of trans-capillary fluid movement, *viz.*, surface area and filtration pressure (6). Consequently less water is filtered through the capillary wall per unit time. Besides, the temperature drop probably reduces the permeability of the terminal capillaries of the skin.

A similar relationship between temperature and permeability has been established by us for erythrocytes (8).

It seems reasonable that these effects fi-

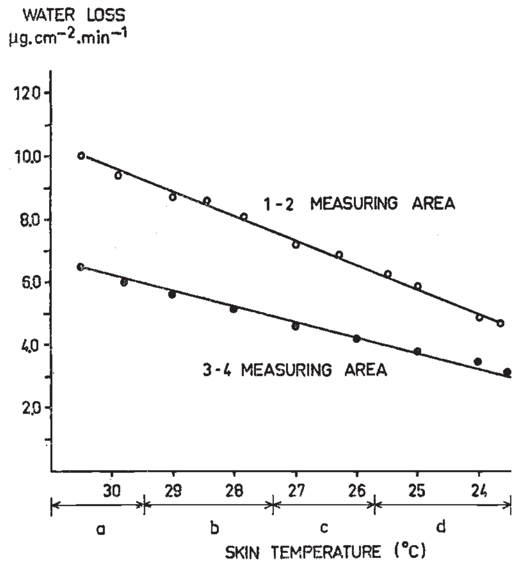

FIG. 6. Relationship between water loss and skin temperature at two measuring areas (between measuring area 1 and 2 and between 3 and 4) under the influence of cooling [Subject B]. Forearm uncovered (a); temperature drop in the climate room (b); fanning of the upper arm (c); fanning of the forearm (d).

nally influence the water loss at the skin surface.

If the ambient temperature is kept constant, equilibrium values for water loss and skin temperature are eventually reached.

The rate at which the water loss follows a temperature change on the skin surface is striking. If the external conditions are suddenly altered, the temperature change does not correspond with the increase or decrease of the water loss to be expected. It appears that this water loss does not instantly reach the level which corresponds with the skin temperature previously recorded.

Fig. 6 emphasizes the relationship between skin temperature and water loss at two different measuring sites. These measurements were carried out during exposure of the subject to low ambient temperature (15° C). The decrease in water loss during this exposure has already been shown in Fig. 3. In the measured temperature-range the points appear to be on a straight line for each of the measuring sites.

Except for some small differences (0.1 to 0.5 $\mu g\ H_2O \cdot cm^{-2} \cdot min^{-1}$) on the left and right forearm, equal water losses and temperatures are recorded at identical measuring areas.

Under constant external conditions, the measurements are reproducible.

Left- or right-handedness of the test subjects was found to have no influence on the extent of the water loss.

In spite of the difference in anatomical structure of the skin of the forearm and the palm of the hand (*e.g.* thickness of the stratum corneum, sweat gland population), the decrease or increase in the water loss on the palm of the hand was found to be proportionally equal to that of the forearm. On both skin areas the water loss finally reaches a constant level at low skin temperatures. The blood flow behaves in a similar fashion (4, 9, 10, 11). Simultaneous measurements of heat loss (calorimetric) and blood flow under steady conditions (10) are in agreement with these observations.

Climatic factors determine the ultimate value of the water loss (12).

SUMMARY

An investigation into the relationship between skin temperature and water loss has indicated that a correlation exists between these parameters. Climatic factors determine the degree of the water loss. It seems justified to assume that the driving force of the water loss is related to the vascular microcirculation in the tissues, which is controlled by vasomotor mechanisms.

The reaction patterns of forearm and palm of the hand are basically equal and the water losses of all skin areas decrease or increase proportionally per degree centigrade. The results of this investigation clearly show that quoting a value for the insensible water loss of the skin without denoting the skin temperature—measured with a constant contact pressure of the thermistor head—and without indicating the measuring site is inadequate.

REFERENCES

1. Thiele, F. A. J. and Schutter, K.: Moisture meters for measuring the water-balance of the human skin. A critical discussion of the Improved Salt Crystal and Electrolytic Moisture Meters. Proc. of the Scientific Sect. of the Toilet Goods Assoc., *40:* 20, 1963.
2. Stoll, A. M. and Hardy, J. D.: Study of thermocouples as skin thermometers. J. Appl. Physiol., *10:* 531, 1950.
3. Fox, R. H. and Edholm, O. G.: Nervous control of cutaneous circulation. Brit. Med. J., *19:* 110, 1963.

4. Hellon, R. F.: Local effects of temperature. Brit. Med. J. *19:* 141, 1963.
5. Pappenheimer, J. R.: Passage of molecules through capillary walls. Physiol. Rev., *33:* 387, 1964.
6. Kitchin, A. H.: Peripheral blood flow and capillary filtration rates. Brit. Med. J., *19:* 155, 1963.
7. Brown, E., Wise, Ch. E. and Wheeler, E. O.: The effect of local cooling on the filtration and absorption of fluid in the human forearm. J. Clin. Invest., *26:* 1031, 1947.
8. de Gier, J., van Deenen, L. L. M. and van Senden, K. G.: Glycerol permeability of erythrocytes. Experientia *22:* 20, 1966.
9. Barcroft, H. and Edholm, O. G.: The effect of temperature on blood flow and deep temperature in the human forearm. J. Physiol., *102:* 5, 1943.
10. Forster, R. E., Ferris, H. B. G., Jr. and Day, R.: The relationship between total heat exchange and blood flow in the hand at various ambient temperatures. Amer. J. Physiol., *146:* 600, 1946.
11. Cooper, K. E., Edholm, O. G. and Mottram, R. F.: The blood flow in skin and muscle of the human forearm. J. Physiol., *128:* 258, 1955.
12. Thiele, F. A. J. and Schutter, K.: Das Wasserbindungsvermögen der menschlichen Haut. Fette, Seifen, Anstrichmittel, *64:* 625, 1962.